Switched Capacitor Based High Gain DC-DC Converter

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ABSTRACT

Grid connected solar PV systems employ DC-DC converters for boosting the PV output voltage to adequate levels. In order to establish an efficient system, a high step-up gain DC-DC converter is presented by combining the switched capacitor and regenerative boost configuration. Since the switched capacitor and regenerative boost operation take place simultaneously the voltage gain and efficiency is improved. It also reduces ripple content, which helps to elongate the lifetime of devices. Moreover, it offers low switching stress across the semiconductor devices. The converter improves the DC –voltage gain extremely especially at large duty ratios. By implementing the high gain dc-dc converter, the size and cost of the whole solar PV system can be minimized.

***KEYWORDS*:** DC-DC converter, Photovoltaic, Grid.

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1. INTRODUCTION

The dc-dc converter is the most promising and attractive converter for renewable energy systems. In solar and wind energy conversion system the generation voltage level is so far from grid voltage. After voltage source inverter (VSI) stage, a transformer is mainly used to step-up the AC voltage to meet grid requirement for effective synchronization. But due to the presence of such grid transformer the whole system losses will increase and hence there will be decrement in efficiency. In order to avoid the use of a transformer, a high step-up gain DC-DC converter is presented by combining the switched capacitor and regenerative boost (SCRB) configuration in this work. In classic boost type and derived converters, the device stresses and losses associated with the converter are high and result in lower efficiency. But in this converter high voltage gain is achieved by the simultaneous switched capacitor and regenerative boost operations. Switched capacitor (SC) converters are the most common solution to achieve high gain. When the switched capacitors are integrated with classic boost type, the DC-voltage gain improves and also the reactive components of the converter increase to attain higher DC-voltage gain. Hence the device stresses and losses of this converter decreases and there will be improvement in the efficiency

The fundamental principle of this converter is to regenerate boosted voltage using switched capacitor and inductor during on-state of the switches. Consecutively, it discharges the reactive elements energy at cascaded form during off-state of the switches. Therefore, this work improves the DC-voltage gain at a high.

V. Karthikeyan et.al [1] presented high step-up gain DC-DC converter with switched capacitor and regenerative boost configuration. The switched capacitor and regenerative boost operations take place simultaneously using lossless passive components and a minimum number of semiconductor devices. Thereby, it drastically increases the DC-voltage gain and enhances efficiency. In addition, it also dominates with fewer ripple content, which helps to elongate the lifetime of devices and suppress the electromagnetic interference. The main goal of this converter is to achieve high DC voltage gain to avoid the use of the transformer in solar PV applications. Tian Cheng et.al [2] proposed non-isolated single-inductor DC/DC converter with fully reconfigurable structure for

renewable energy applications. The purpose of this topology is to integrate a regenerative load such as DC bus and motor with dynamic braking, instead of the widely reported consuming load, with a photovoltaic (PV)-battery system. Conventional methods require either a separate dc-dc converter to process the reversible power flow or employing an isolated three-port converter (TPC) which allows bi-directional power flow between any two ports. However, these methods require many switches which increases the converter size and control complexity. Boris Axelrod et.al [3] introduced switched-capacitor/switched-inductor structures for getting transformerless hybrid DC-DC PWM converters. A few simple switching structures, formed by either two capacitors and two-three diodes (C-switching), or two inductors and two-three diodes (L-switching) are proposed. These structures can be of two types: step-down and step-up. These blocks are inserted in classical converters: buck, boost, buckboost, Cuk, Zeta, Sepic. The step-down C- or L-switching structures can be combined with the buck, buckboost, Cuk, Zeta, Sepic converters in order to get a step-down function. The main advantage of the new converters is their lower energy in the magnetic elements, what leads to weight, size and cost saving for the inductors,and thus for the power supply,and less conduction losses, what leads to a better effciency.

Yong Cao, Vahid Samavatian et.al [4] proposed a novel non-isolated ultra- high voltage gain DC-DC converter with low voltage stress. Regarding to the inherent structure of some non-polluting resources such as fuel cell stacks and photovoltaic panels, the output exhibits a low voltage which cannot be employed in the common conventional utilizations. Accordingly, an interference DC-DC converter is extremely required. This paper demonstrates the feasibility of using an ultra-high voltage gain DC-DC converter in either the fuel cell or the photovoltaic applications. While keeping high voltage gain, this topology illustrates low switching voltage stress resulted in high efficiency.

Hongfei Wu et.al [5] gave the idea of an energy efficient charging technique for switched capacitor voltage converters with low duty ratio. Charging a capacitor array of a switched-capacitor (SC) DC-DC converter, supplying load circuits with a very short active period, can be pivotal to achieve high energy efficiency of its operation. This is because the capacitors may lose most of the stored energy during a long sleep period, and thus every sleep-to active transition requires full recharging of the capacitors. In this work, an energy efficient capacitor charging technique called split-capacitor charging, which charges a capacitor array in a step-wise fashion is presented.

Jian-Hsieng Lee et.al [6] describes a isolated coupled inductor integrated DC- DC converter with non-dissipative snubber for solar energy applications. The proposed converter realizes high step-up voltage gain without incurring a high coupled inductor turns ratio by adapting a dual-voltage doubler circuit. In addition, the energy in the coupled inductor leakage inductance can be recycled via a non-dissipative snubber on the primary side. Thus, the system efficiency is improved. This work has presented an isolated coupled inductor converter with a non-dissipative snubber to reduce the voltage spike on switches and to recycle leakage energy. This converter can achieve high step- up voltage gain with a low coupled inductor turns ratio. The low turns ratio is achieved by decreasing the size of the coupled inductor

In order to overcome the problems pointed in above papers a high step-up gain DC-DC converter with switched capacitor and regenerative boost configuration is introduced combining switched capacitor and regenerative boost configuration. The main goal of this converter is to achieve high DC-voltage gain by avoiding the use of the transformer in solar PV applications due to cost, size and weight

2. Proposed converter Configuration

The PV system normally uses transformer which may be of high cost, size and weight. Hence transformer become the primary burden in grid-connected solar PV-system and it decreases the whole system efficiency. Normally the switched capacitor networks are used to improve the voltage gain in an efficient manner. Hence goal of this work is to improve the voltage gain by regenerating the boosted voltage using switched inductor and and capacitor during on state of the switches. During the off state of the switches, the reactive elements will discharges consecutively. Hence voltage gain increases to an extreme level

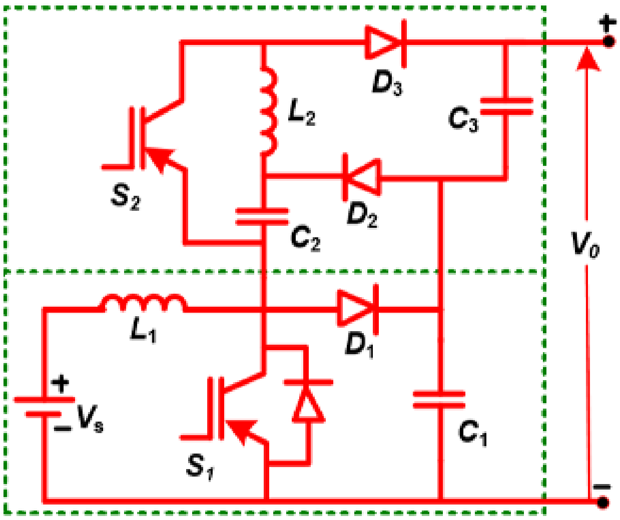

Fig -1: Circuit Diagram of Proposed Converter

High step-up gain DC-DC SCRB converter contains two active switches S1, S2, inductors L1, L2 and diodes D1, D2 and D3. It also consist of capacitors C1, C2 and C3. The inductor L1 and capacitor C1 are used to perform boost operation. According to the proposed structure, the boosted voltage is regenerated and further stored into capacitor C2 and inductor L2. The energy stored in C2 and L2 is controlled by the switches S1 and S2, respectively. The fundamental principle of this converter is to regenerate boosted voltage using switched capacitor and inductor during on-state of the switches. Consecutively, it discharges the reactive elements energy at cascaded form during off-state of the switches. Therefore, this converter improves the DC- voltage gain at an extreme level. Figure1 shows a circuit of typical arrangement of the discussed high gain DC-DC SCRB converter.

CCM MODE OF OPERATION

The detailed steady-state analytical waveforms and circuits under CCM operations are illustrated below.

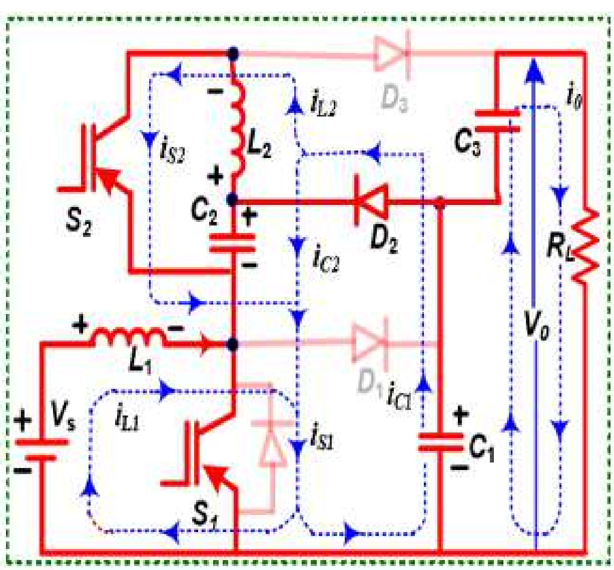

Fig-2 CCM Operation Mode1

MODE 1(t0-t1)

At instant , $t_0$the switch S_1 is turned on and the inductor L_1 stores the energy till t_1. At the same time, C_1 gets discharged toL_2 through switch S_2. This is called regenerative boost operation. Simultaneously, C_1 gets discharged to C_2 a□d it is called switched capacitor operation. The change in slope of $L_1$and L_2during gating signals of S1 and S2 are clearly depicted in Fig. 1. The equivalent circuit during mode 1 is shown in Fig. 2.

MODE 2 (t1-t2)

At instant t1, the switch S2 gets turned off, but still S1 is on state. Therefore, L2 and C2 get discharges the energy to load. The current paths are clearly depicted in the circuit as shown in Fig. 3. During this interval, the inductor currents and voltages are clearly illustrated in Fig. 5. The equivalent circuit during mode 2 is shown in Fig. 3

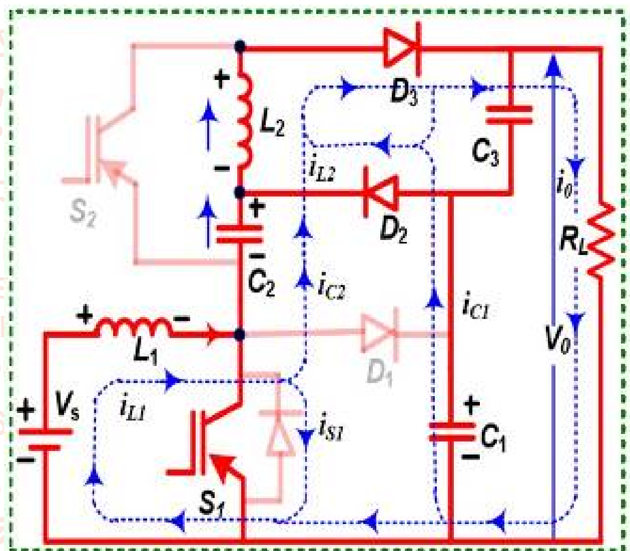

Fig -3: CCM Operation Mode 2

MODE 3 (t2-t3)

At instant t_2, the switch S_1 gets turned off, the stored energy in L_1, L_2, andC_2 is discharged along with the source to the load. Due to this cascaded operation, the output voltage gets increased drastically. Here, C_1 and C_3 act as filter network. For better insight, the current paths during this particular interval are clearly marked in the equivalent circuit as shown in Fig. 4.

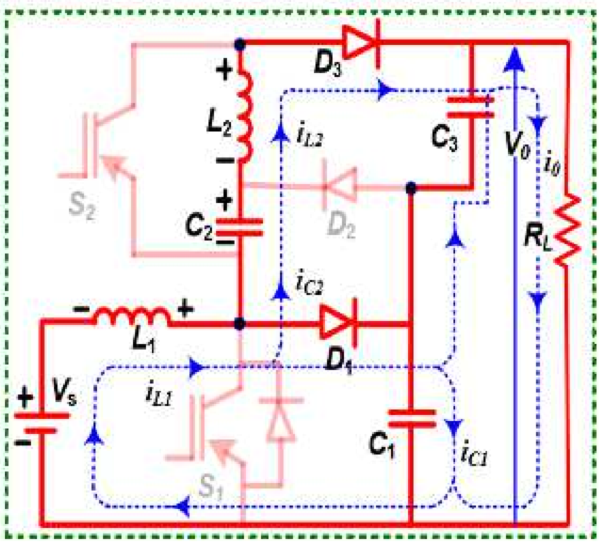

Fig -4: CCM Operation Mode 3

The wave forms of Continuous Conduction Mode (CCM) is shown in Fig. 5.

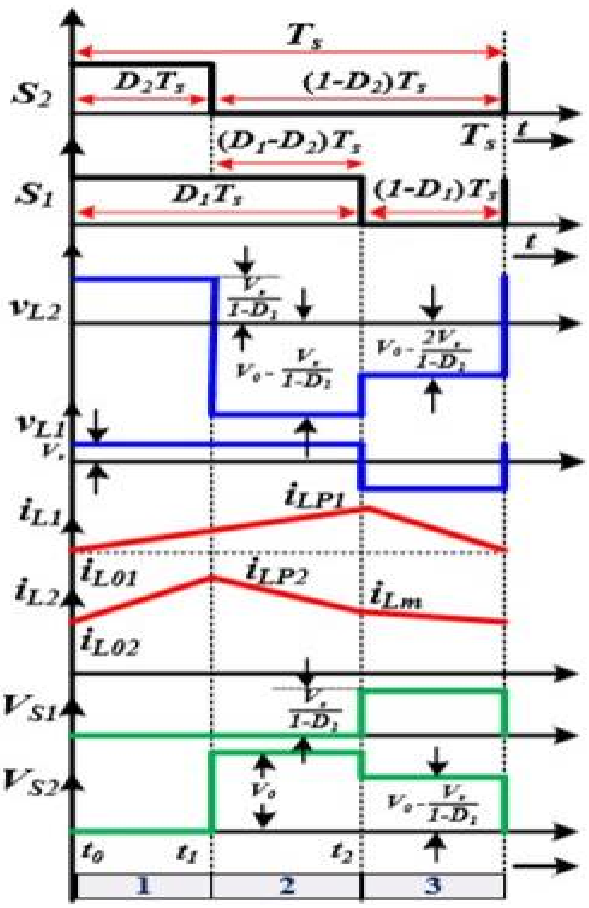

Fig -5: Theoretical operating wave forms

DCM MODE OF OPERATION

The steady state analytical waveform under DCM operation is illustrated in Fig. 7. From this figure, it is clear that the inductor current becomes discontinuous and attains zero state at instant $t3$. Four operating modes are identified in DCM operation. The first three modes are same as in continuous mode of conduction

MODE 4

At instant t_3 S_1 gets turned off and i_{L1} starts falling and reaches to zero at instant t_4. After this instant t_4, C_1 and C_2 discharge the energy to load and the corresponding circuit representation is clearly depicted in Fig 7.The equivalent circuits before and after i_{L1} reaches to zero is shown in Fig 6 respectively.

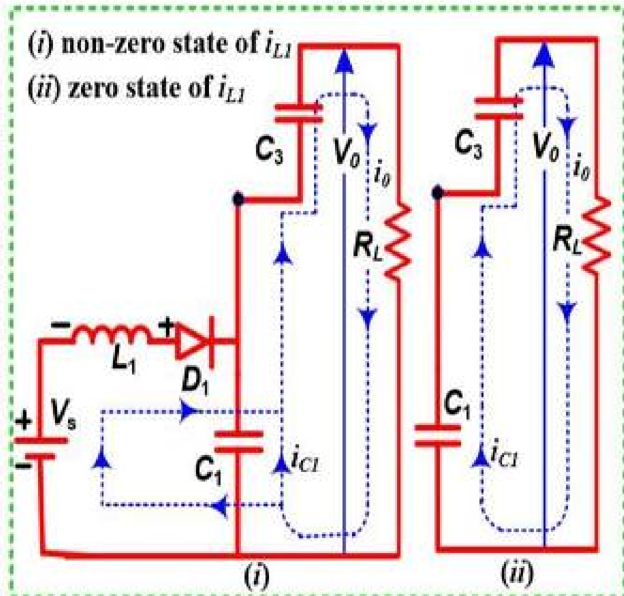

Fig 6: DCM operation Mode 4

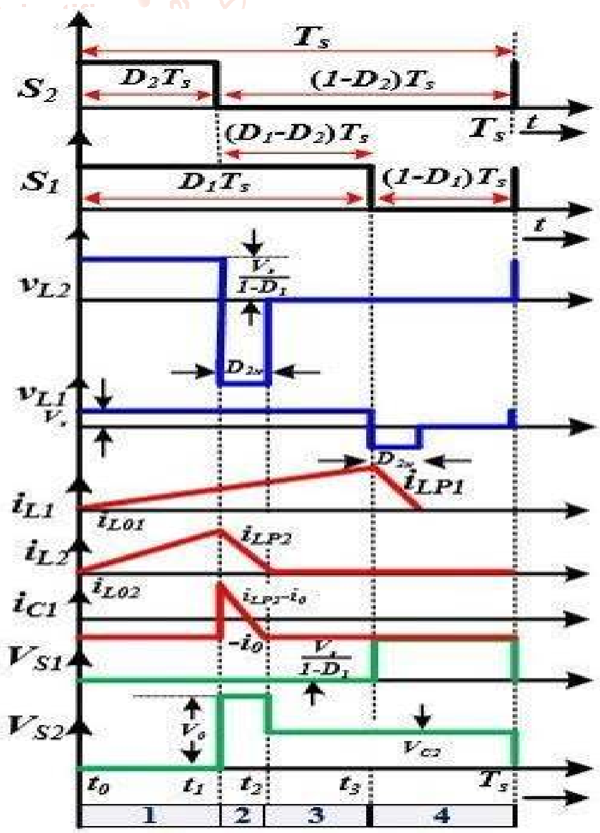

Fig -7: Waveforms of DCM Operation

3. DESIGN OF SCRB CONVERTER

The high step-up gain DC-DC converter is designed for input voltage 31 V with a duty ratio of 0.8.Beyond

this duty cycle, the inductore core is saturated and generates noise in the circuit. The converter operates at 10kHz for an output power of 100W.

For any practical applications, the dc-dc converter must be operated at lower duty ratios to get maximum efficiency and the duty ratio can be extended up to 0.8

Taking Po as 100W, load resistance is calculated as

$$\text{Load Resistor, } R = Vo2/Po$$

Let the ΔiL be the ripple in input side inductor. In order to find this find ripple current we need the output current

$$L1=L2 \geq D(1-D)Vo/\ (3+D)\Delta l\ f$$

4. SIMULATION

The proposed topology of the converter is simulated in MATLAB using the parameter listed in Table.

Table -1: MATLAB Parameters

COMPONENTS	SPECIFICATIONS
Input voltage	31V
Output voltage	268 V
Rated power	100W
Switching frequency	10 kHz
Inductors	1mH
Input capacitors	20µF
Load resistor	700 Ω

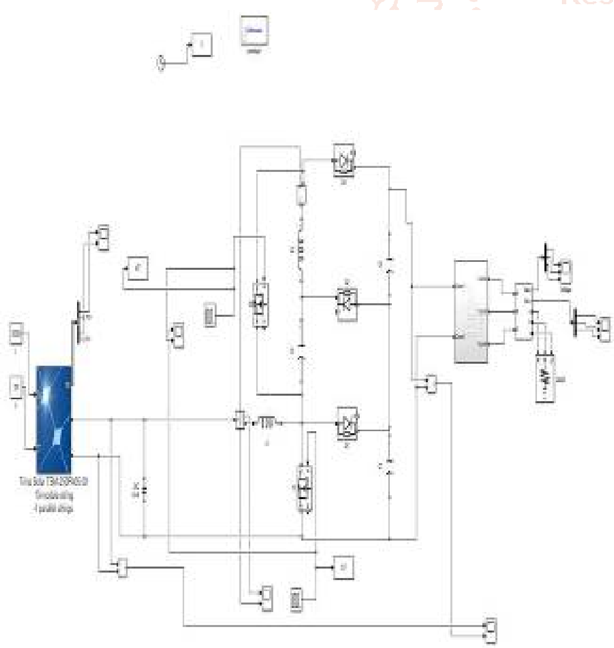

Fig -8: Simulation of proposed converter with solar PV

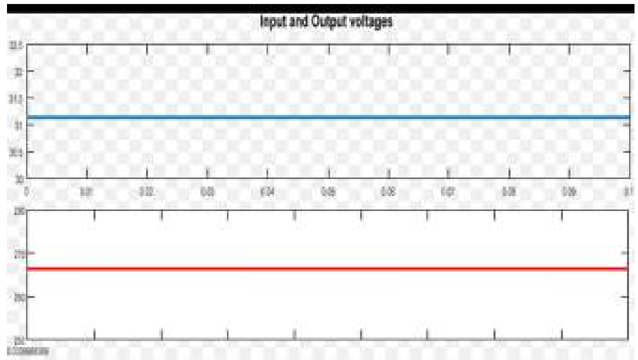

Fig -9:Input Voltage & Output Voltage

5. CONCLUSION

High step-up gain DC-DC converter with switched capacitor and regenerative boost configuration offer high gain and improved efficiency. In the interleaved converter, the switched capacitor and regenerative boost operations take place simultaneously using passive components and a minimum number of semiconductor devices.

Thereby, it increases the DC voltage gain and enhances efficiency. In addition, it also dominates with fewer ripple content, which helps to elongate the lifetime of devices. The main goal of this converter is to achieve high DC voltage gain in traction applications even when the input voltage is low from the solar PV panel sources. For the converter, the voltage gain is about 30. The converter has an efficiency of 91.8% with a duty cycle of 80%. Beyond this duty cycle, the inductor core is saturated and generates noise in the circuit, which automatically degrades the performances.

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